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# 3D Printing and Retail

## The Effects of Additive Manufacturing Techniques to the Retail Market in the Next Decade

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Abstract


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The thesis takes a practical approach to assess the uses of 3D printing on both consumer and professional levels, tries to identify the type of internal processes in retail where 3D printing could be used, and the threats and opportunities 3D printing creates to retail.

The first part of the thesis, the overview of 3D printing, explains what 3D printing is, finds out about its history, categories, current and future applications, expected diffusion rate, the advantages and disadvantages 3D printing has over traditional manufacturing, what challenges it faces, and finally what experts think of its effect to retail.

The second part of the thesis consists of information and opinions gathered from professionals in the retail industry on how they view 3D printing.

Finally the thesis contrasts the information from both the overview and the interviews to build an accurate picture of the present state and the near future of 3D printing.

The effect of 3D printing to retail is found to be moderate at best. Though 3D printing will allow more small businesses to enter the market of manufactured goods and greater customisation of products, the majority of goods will be mass produced and sold by means of traditional retail.



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| Keywords | 3D Printing, Additive manufacturing, Retail |

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## 1 Introduction

The motivation for this thesis came from the first chapter of Timo Paukku's book Kymmenen uutta ihmettä – teknologiat, jotka muuttavat maailmaa.

The chapter discusses the emergence of 3D printing and what applications it will have in all of our day-to-day lives.

As a professional in the retail industry, the author set out to find out how 3D printing could affect retail in the next decade. The thesis takes a practical approach to assess the uses of 3D printing on both consumer and professional levels, tries to identify the type on internal processes in retail where 3D printing could be used, and the threats and opportunities 3D printing creates to retail.

The first part of the thesis, the overview of 3D printing, explains what 3D printing is, finds out about its history, categories, current and future applications, expected diffusion rate, the advantages and disadvantages 3D printing has over traditional manufacturing, what challenges it faces, and finally what experts think of its effect to retail.

The second part of the thesis is a qualitative study and consists of information and opinions gathered from professionals in the retail industry on how they view 3D printing.

Finally the thesis contrasts the information from both the literature review and the interviews to build an accurate picture of the present state and the near future of 3D printing.

## 2 Overview of 3D printing

In this chapter we look at what 3D printing is, find out about its history and categories, and what its applications are currently. We then find out what some of the experts in the field think about the future of 3D printing and what the expected diffusion rate for it is both in consumer and professional use. After that the thesis will discuss about the advantages 3D printing has over traditional manufacturing, where its limitations are and what challenges it faces. Finally we find out what experts think of its effect to retail.

### 2.1 Definition of 3D printing

Additive manufacturing, colloquially known as 3D printing, is an umbrella term for technologies that allow the production of physical goods from the ground up. Where traditional fabrication tools - such as lathes, saws, drills and rototillers - take a chunk of raw material and trim it down to form a shape (subtractive manufacturing), a 3D printer does the opposite. As the technical term suggests, 3D printers add raw material one tiny layer at a time eventually fabricating an entire object. Unlike plastic injection moulding, a 3D printer does not require a costly mould, only a digital design file containing the information of the desired object. Consequently, 3D printing is the first manufacturing method that allows the production of intricate designs with hollows and interlocking parts (Lipson & Kurman 2013a: 11-17).

### 2.2 History of 3D printing

The first 3D printer was developed by an American engineer Charles Hull in 1984. He had been studying photopolymers, plastics that can be hardened with light, when the idea struck him to build a device that would allow the user to harden a thin layer of plastic after another, gradually building a desired object. Hull dubbed this new method of manufacturing stereolitography and applied for a patent to both the technology and the device he built (Paukku 2013: 24). Hull then went on to found 3D Systems in 1986, which is still the largest manufacturer of 3D printers in the world with market capitalisation of $3.75 billion in January 2013.

The second major player in the 3D printing industry, Stratasys, has very similar beginnings. The company was founded in 1989 by Scott Crump, following his invention of fused deposition modelling (FMD; see appendix 1) the year before. Nowadays Stratasys is very similar in scale to 3D systems with share value of $3.52 billion in January 2013 (Barnatt 2013: 74-78).

3D printing is sometimes called rapid prototyping. This is because historically the main use of additive manufacturing techniques has been to build prototypes or scale models of products, or parts thereof, before they go into production. The word "rapid" here can be somewhat misleading as the more complex builds can take from hours to days to print. However, compared to making the prototype by hand or to actually making a mould of the designed object, tooling the machinery and producing can take much longer, making 3D printing the rapid solution. And, of course, the whole idea of building a prototype is to avoid the cost of the mould and tooling in case the design needs to be revised (Gershenfeld 2005: 99-101).

## 2.3 Categories of 3D printing

As previously mentioned 3D printing is an umbrella term comprised of several different technologies. There are some dozen or so 3D printing methods, which can be classified in three main categories, each with their own strengths and weaknesses. For a more detailed description of the different categories see appendix 1.

The technologies in the first category are based on extrusion of molten or semi-liquid material through a print head nozzle into a desired shape. This category is called "material extrusion" and most of the consumer level devices available fall under it. Though any material that can be extruded trough a syringe and that will hold a shape afterwards can be 3D printed this way, most material extrusion printers use thermoplastics as their filament. Some of the 3D printers in this category have several print heads enabling the use of multiple materials in one job.

In the second category, known as “photopolymerization”, 3D printers use lasers or other light sources to solidify, or curd, liquids known as photopolymers. Stereolitography mentioned in chapter 2.2 falls under this category. In some processes the light source traces the desired shape in a vat of photopolymer resin, whereas in others the shape of the entire layer is projected onto the resin and let to solidify at once. In some applications the photopolymer is sprayed and cured directly into the desired shape. There are a couple consumer level 3D printers that use photopolymerization, but for the most part the 3D printers in this category are in professional use.

Finally there is “granular materials binding”. Here the 3D printer fuses very fine powder together, using a laser or a binder, to form an object. The printers in this category typically have a large powder reservoir adjacent to the actual print platform. A roller spreads a thin layer of the powder to the print platform and the desired shape is traced with the laser or the binder. Once the first layer is done the platform lowers and the next layer of powder is applied. The printers in this category can use plastics, metals, ceramics or even glass as their print material. Currently there are no consumer level 3D printers that use granular materials binding. (Barnatt 2013: 4-6, 26-68; Lipson & Kurman 2013a: 68-84)

## 2.4 3D printing presently

The current users of 3D printers can be divided into two main categories; professional users and enthusiastic tinkerers. Both these groups are advancing the technologies in their own ways. The professionals can be found in several different industries including construction, medicine, engineering, aeronautics and chocolatiers where they have found new innovative uses for 3D printing. The tinkerers have pushed consumer level 3D printers forward by open-sourcing software and hardware as well as sharing their designs online.

The number of 3D printers sold annually increased steadily since the invention of the technology until 2010 when the number of units sold suddenly grew 67% from 6000 units sold to 10000 units sold. In 2011 consumer level 3D printers first sold more units than professional level devices (Lipson & Kurman 2013a: 34). According to Gartner

(2013) the sales of 3D printers priced under $100,000 exceeded 56,500 units in 2013 and are estimated to sell nearly 100,000 units in 2014.

### 2.4.1 Professional 3D printing

The two industry leaders, Stratasys and 3D Systems, dominate the field of professional level 3D printers. They manufacture 3D printers in all three technology categories, sell a wide range of printing materials guaranteed to be compatible with their printers, and offer support services for their customers.

The current 3D printers that are in professional hands are only rarely used to create final products ready to use (see figure 1). At the moment only one out of five prints is a final product. Instead they are mainly prototypes or scale models, or sometimes masters used to create a mould for casting.

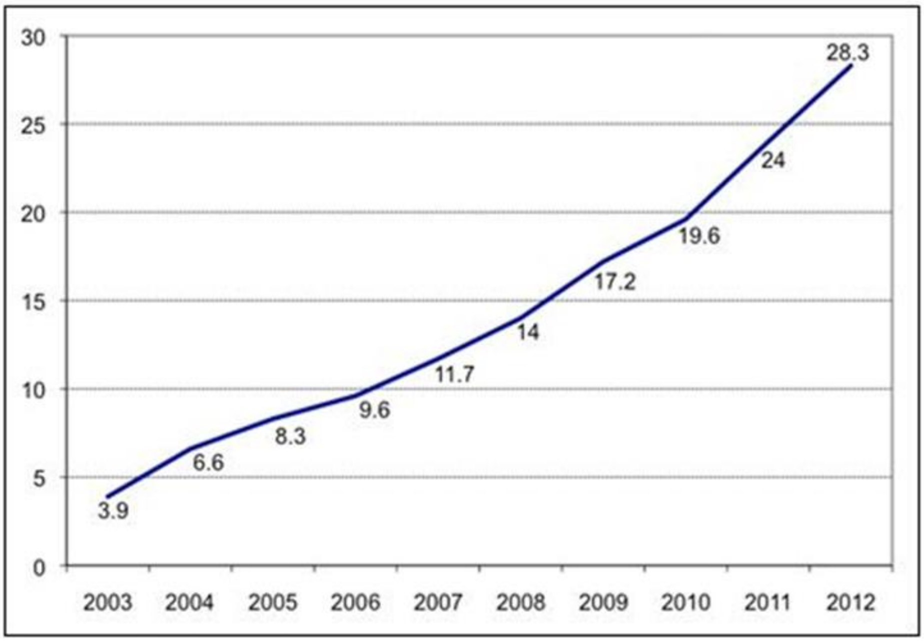


Figure 1: Share of final parts production of 3D printing products and services worldwide (Wohlers Associates 2013a)

The aforementioned final products include components to be used in other objects, such as airplane parts, hearing aid casings, or elaborate ornamental eye catchers on design clothes (Paukku 2013: 20-29). Though 3D printing has traditionally been a tool for industry and academia, it has recently become an integral part of many nontechnical professional’s arsenal. Medical researchers have recently received much attention from the press with several 3D printed implants including jaw bones and prosthetic limbs. At the time of writing this the world’s first 3D printed house is being built and had by the end of February 2014, within two months of construction, received over 2000 visitors ranging from architecture students to building contractors, and even president Barack Obama of the United States (Wainwright 2014).

The 3D printed final products created by professionals that are commercially available at the moment are mainly novelty items. In Japan an expecting woman can have an ultrasound of her foetus turned into a 3D printed plastic souvenir by her doctor. Several design companies print furniture and decorative items that include shapes and hollows that would be hard or impossible to manufacture by conventional means. The sex industry has already found 3D printing as well. There are currently companies online that allow their clients to customise their own sex toys and either have them shipped to them or let them download the design to be printed at their convenience. The significance of the sex industry should not be underestimated. After all several people have credited its influence in the VHS win over the technically superior Betamax in the VCR race and the subsequent rapid development of online video streaming (Lipson & Kurman 2013a: 61-62).

### 2.4.2 Consumer level 3D printers and the maker movement

The consumer level 3D printer market only appeared mid 2000s thanks to the so called maker movement; enthusiastic tinkerers and DIY hobbyists that have adopted the tools of the digital age. Before that all 3D printers were expensive and proprietary professional devices. However, that all changed after the makers took interest in 3D printing and, being part of the Web generation, promptly shared their designs, knowledge, and ideas and collaborated with like-minded individuals and groups in specialised online communities, hackerspaces and fab labs (Anderson 2012: 20-21). This open-sourcing of hardware has led to there being much more players in the consumer level than the professional level.

The two largest companies, though, have a significant standing on the market. 3D Systems launched their Cube printer in 2012 and have since expanded this brand with several newer models. 3D Systems has the advantage of horizontal integration on their side. In recent years they have acquired tens of smaller companies in the industry (some of these were merged with 3D Systems but many continue under their own company name as a 3D Systems subsidiary). Nowadays the company does not just manufacture the printers but also provides the proprietary filaments for them, design software for the consumers to create their own prints, as well as cubify.com – a website where designers can sell their products to the public (Barnatt 2013: 74-76). Stratasys gained a significant foothold in the consumer market in late 2013 by acquiring MakerBot, at the time one of the largest companies on the market by sales volume. Before this Stratasys had focused on high-end industrial clients and had no real presence in the consumer market.

Many of the companies on the market have their roots in the RepRap, a project that aims to ultimately create a machine that can not only print a myriad of other objects but also completely replicate itself (many of the parts can already be replicated and the rest are available in any well stocked hardware store). The companies have incorporated the RepRap resources in their own design and sell their printers under their own brand name while keeping their hardware open-source. The printers descending from the RepRap project range from very simplified models that cost a couple of hundred euros to premium models that cost a couple of thousand. The companies sell their printers both fully assembled, plug-and-play setups as well as kits that the buyers can put together themselves (Griffin et al. 2013). According to a survey on the 3D printing community by Jarkko Moilanen and Tere Vadén (2012) a third of individuals using 3D printers have used either MakerBot or some other printer seeded by the RepRap project.

A good insight of consumer printing habits can be gained by viewing the popular items section on MakerBot Thingiverse (2014). The site allows users to share their designs with the community, who can then comment on them, like them or even print them with their own device. The most popular designs include functioning items usable right away after printing such as scissors, wrenches, smart phone and tablet covers and stands, toothbrush holders, nut crackers, clips, brackets, buckles, and slinkies. There are also many decorative items for example lamp shades, models of famous sights such as the Eiffel tower and Abraham Lincoln’s statue, vases, TARDIS miniatures with drawers, and busts of Batman, Yoda and Gollum.

## 2.5 Future of 3D printing

Many of the papers describing the future of 3D printing start by mentioning the fabricators in the late 80s early 90s sci-fi series Star Trek: The Next Generation. As Captain Jan-Luc Picard of the USS Enterprise orders a: “Tea. Earl Grey. Hot.” the fabricators materialize, through a process that is never really explained, not only the tea but the tea set as well. The papers are then quick to mention that the real life 3D printers will not be able to do anything like the fictional replicators, at least not in any foreseeable future.

The outlook for 3D printing varies radically depending on who you ask. While some view that the technologies will largely remain in the hands of professionals others proclaim a next industrial revolution, where the means of production are accessible to all in the form of personal fabricators.

Hod Lipson, professor of engineering in Cornell University, believes strongly that 3D printing will, within a couple of decades, be an integral part of everyone’s day to day life. In his book Fabricated (2013: 1-5), co-authored with Melba Kurman, he paints a picture of a future where health insurance company licenced medical-grade food fabricators wirelessly read your vitals from an implanted chip and balance the sugars and nutrients on your food accordingly to manage your diabetes. A future where bioprinting replacement organs has become commonplace, and where, rather than going out to a store to buy one, a toothbrush can be fabricated at home with customised features such as a grip modelled after the user’s hand measurements.

Lipson has a unique insight in the development of consumer level 3D printers as he is one of the co-founders of the Fab@Home-project. The project is very similar to the aforementioned RepRap as it was started around the same time, is completely open source, and helped in creating an access for the technology for consumers. Unlike RepRap which is based on thermoplastic extrusion, however, the Fab@Home 3D printers use a syringe extruder that enables them to print in a wider range of materials. As Lipson has personally been involved in the creation of the consumer level 3D printers and has on the first hand seen his 3D printer to produce items such as functioning batteries, titanium jaw bone implants, and edible fried scallops that are shaped like cogs, it is easy to see why his point of view is that within the foreseeable future 3D printers, or personal fabricators, will be as commonplace in private households as computers are today.

In a blog post on Big Think Lipson and co-author Melba Kurman (2013b), a technology analyst and business strategy consultant, compare predicting the future of 3D printing to what people in the 70s could have predicted of the computers of today – while some things can be said with a fair amount of certainty, there are unknowable factors that will affect the end result. New technologies that no one has yet even conceived can revolutionise 3D printing like the Internet with personal computers.

Chris Andeson, the editor of *Wired* magazine, outlines in his book Makers – The New Industrial Revolution (2012) a future where everyone can be a manufacturer. Anderson argues that the ability to manufacture almost anything at home will revolutionise economy as we know it. He argues for DIY manufacturing, where everyone can take part in the manufacturing industry from the comfort of their own home. He draws a parallel to the cottage industries of old, when artisans created products at their home to be sold or traded for other goods. Anderson sees this type of manufacturing becoming if not the new norm at least very much an important part of the economy.

Christopher Barnatt (2013), a futurist and an associate professor in Nottingham University, has a more conservative outlook on the future of 3D printing. He believes that as a manufacturing technology on industrial scale it will remain limited to high value, low-run, or customised parts and products. He estimates that 3D printing will change approximately 20% of all manufacturing, and like typewriter and subsequently PCs in regard to pen and paper, will not replace the current manufacturing methods but rather supplement them.

He also puts himself at odds with Lipson, who believes food printing to be one of the most important applications and a corner stone of 3D printing; he even calls it the "killer app" of 3D printing – the use that will bring home 3D printing to mainstream.

Barnatt argues that people will not adopt the idea of printing food. Firstly he feels that extruding unprepared food stuff that still requires some sort of cooking is ineffective and resource intensive. Secondly he argues that people who can already prepare food on their own, or at least order it from a restaurant, do not require a machine that would likely make the process more expensive. He goes on to state that: "Yes, a few gadget freaks will love the idea of spending the weekend printing out a slice of bread. But a mainstream technology in the waiting? Give me a break."

Most of the more advanced 3D printers Barnatt places in either professional settings or 3D printing bureaus that offer printing services to customers. He dismisses the idea that 3D printers for home use could print ceramics or metals. These materials will be more likely either used by professionals, or printed in the printing bureaus.

Barnatt does, however, think that the future of simple plastic products is to be printed at home. He argues that due to the scarcity of petroleum and other resources, a girl in 2030s will not have the option of going to a store to buy a doll that was mass produced in China, but will have to print one at home or local 3D printing bureau. Barnatt predicts that the near future is marked by competition for the limited resources, which will in turn lead to production localisation and increase of the domestic manufacturing base in the western countries.

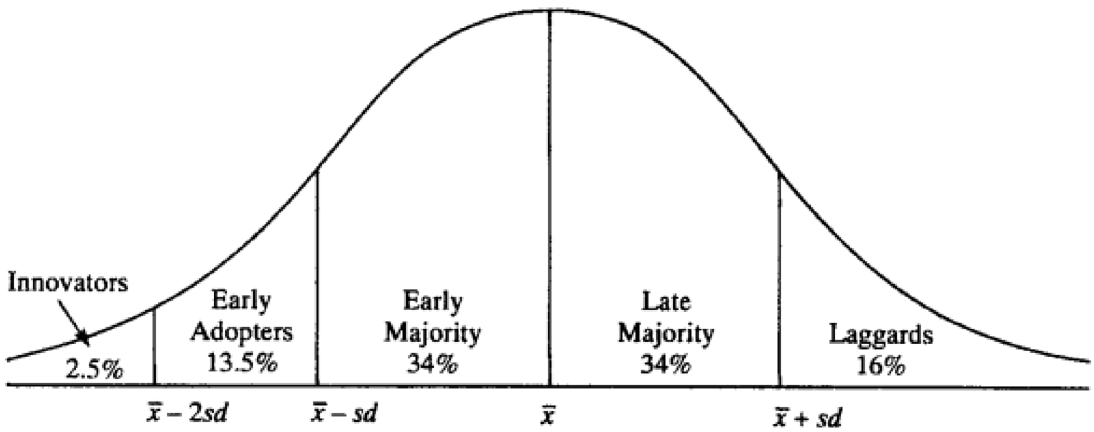
## 2.6 Diffusion of 3D printers

Considering that 3D printing has existed already for three decades it has a very low adoption rate. Currently additive manufacturing is approximately a $3 billion industry, which is nothing, compared to the scale of the manufacturing industry as a whole which is worth some $15 trillion (Lipson & Kurman 2013a:35).

### 2.6.1 Diffusion of innovations

So far 3D printing has only been adopted what Everett M. Rogers (2003) in his theory on the diffusion of innovations described as innovators (see figure 2). This group, comprising usually 2.5% of the market, contains the most venturesome of the consumers. They have enough money to invest in a new innovation and the willingness and tenacity to learn how to use it. However, as the number of devices sold increases – the sales of 3D printers that cost less than $100,000 grew 49% from 2012 to 2013, are expected to grow 75% in 2014, and nearly double in 2015 (Gartner 2013) – and the printers become more user-friendly, better quality and less expensive we are entering the time of the early adopters.

Figure 2: Adopter categorisation based on innovativeness; share of population




(Rogers 2003: 281)

The early adopters are critical for the consumer to accept an innovation. They are usually the opinion leaders that can influence the potential adopter's decisions by stamping their seal of approval on the technology. Early adopters help the innovation gain the critical mass it requires to become widely accepted. After gaining the critical mass the adoption becomes self-sustaining and the innovation will eventually spread across the market.

The next vital step for the diffusion of consumer level additive manufacturing is to get the 3D printers out to the marketplace. At the moment nearly all consumer level 3D printers are sold directly by the manufacturer via their website, making it unlikely that an average consumer will ever stumble upon them. This, however, is starting to change. Gartner (2013), a US based information technology research and advisory company, expects that seven of the 50 largest global retailers will have 3D printers in their selection by 2015.

### 2.6.2 What experts expect

Wohlers Associates (2013b), a consulting firm and one of the leading organisations in analysing the 3D printing market, sized additive manufacturing to be over a $2 billion industry in 2012. They forecast that it will reach $4 billion in 2015 and grow approximately $1 billion annually exceeding $10 billion by the year 2021.

Terry Wohlers himself is cautious when it comes to consumer level 3D printers. He has said that most people will never own or operate a 3D printer. Although people are happy to purchase 3D printed custom goods, they will prefer to get them either from a 3D printing bureau or a traditional retailer (Lipson & Kurman 2013a: 40).

Founder of *Make:* - magazine, Dale Dougherty, is very sceptical about the future of 3D printers and how consumers will adopt them. In a blog post on his magazine's website Dougherty (2013) compares 3D printers to jet skis and espresso makers. He feels that the consumers will see them more as toys rather than tools.

According to Peter Marsh (2012: 60-61), a former manufacturing editor of Financial Times, many experts believe 3D printing to be a mainstream part of manufacturing by 2040. Due to the properties of additive manufacturing, companies will use the technologies to differentiate themselves in the market by adding variety to their products with virtually no extra cost.

### 2.6.3 Recent events that affect the diffusion

In early 2014 two things happened that have the potential of accelerating the diffusion of 3D printing to new heights. Firstly, there was the lapse of the patent of selective laser sintering (see appendix 1). The technology now being open for anyone to use, will likely lead to several new companies manufacturing SLS printers. A similar thing happened when the patent for fused deposition modelling lapsed in 2009. SLS has the advantage over other 3D printing technologies that it can create ready-to-use metal objects, and a sudden influx of affordable SLS printers could make the technology available for a whole number of SMEs that work with customised metal parts. It will also speed delivery times at the 3D printing bureaus, which currently typically suffer from a backlog of several weeks because they cannot afford to own multiple SLS printers per location.

Secondly Hewlett Packard, one of the market leaders in 2D printing, announced in its annual shareholder meeting that it will enter the 3D printing market by the end of this fiscal year, which in HP's case means October 31st. Although HP announced that they will focus on the more high-end, professional level devices, its mere presence on the industry will help to make 3D printing more established and believable in the eyes of the consumers. Furthermore, the company is larger than the current two market leaders combined and can invest heavily on R&D which, combined with HP's existing massive production facilities, can help to bring down the prices of 3D printers and lowering the barrier for the consumer to adopt the technology.

## 2.7 Advantages of 3D printing over traditional manufacturing

Additive manufacturing offers several advantages over subtractive methods and plastic injection moulding. It produces less waste, allows the production of smaller batches, allows for mass customisation, and has zero lead time.

### 2.7.1 Less waste

Machining metal is unbelievably wasteful. An estimated 90% of the original raw material ends up discarded on the factory floor. The metal that is ground off of the original chunk of raw material incurs not only purchasing costs but also waste disposal costs.

An additive manufacturing technology, such as SLS, only uses the amount of raw material necessary for the fabrication of the desired product. In some cases it might be necessary to work a printed object further producing some waste, but in any case the amount of waste is significantly less than that created by machining (Lipson & Kurman 2013a: 22).

Apart from cost there are also environmental considerations. The removal of the raw material used in manufacturing from the earth requires energy. The production of this energy usually leads to carbon dioxide emissions. Peter Marsh (2012: 119-133) argues that there will be significant pressure to reduce waste and energy consumption in manufacturing in the upcoming decades.

### 2.7.2 Small or single unit production runs

Mass production is a volume game. It has very high initial costs and therefore only becomes profitable after a certain amount of units have been produced and sold. The more units the factory produces, the lower the average cost. This is called economies of scale (Dawson et al. 2006: 59). The initial costs come from the tooling of the machinery and, in case of plastic injection moulding, the production of the mould itself.

It would make no economic sense to use mass production technologies to produce a single unit just once. The unit cost would be massive. According to Chris Anderson (2012: 87-89), however, 3D printing is ideal for manufacturing small batches. Anderson states that additive manufacturing does not benefit from economies of scale; the unit cost of the one millionth product will be the same as that of the first one. On the other hand there is no penalty for manufacturing just a few units or even making every unit different.

Additive manufacturing cannot compete with mass production technologies when it comes to making large quantities of identical product. What it does is to offer a manufacturing method to niche products that earlier could not have been mass produced due to too low demand and were not feasible to create by hand as that would have been too expensive.

Lipson and Kurman (2013a: 25-29) concur with Anderson in regard of 3D printing offering no economies of scale. They also remind that economies of scale are only important if a company's strategy is to produce a large number of units with razor thin margins. If the company, on the other hand, is in the business of creating unique design products or custom-made products that have high margins it could benefit significantly from additive manufacturing.

A good example of small production runs in use is given by Christopher Barnatt (2013: 11-12). Apparently the makers of 2012 James Bond-movie *Skyfall* needed three miniature Aston Martin DB5s to be blown up. These replicas that were 1:3 scale models were produced using a 3D printer.

### 2.7.3 Mass customisation

In the world of additive manufacturing complexity and variety are free. The cost of producing ten unique items costs the same as making ten identical ones. The fabrication of an elaborately decorated ornament costs the same as the printing of a solid plastic cube (Anderson 2012: 88-89).

This property of 3D printing allows for what is known as mass customisation. Christopher Barnatt (2013: 10-11) mentions a company called ThatsMyFace.com. The clients of the company can create a 3D model of their head by uploading a frontal and a side-profile photo of themselves. Their head can afterwards be printed out and fitted to one out of a selection of mass produced plastic action figures.

The medical and dental industries are already frequent users of customised, 3D printed products. Every single person has a different body structure meaning that identical, mass produced goods will not fit all. This has created a market for tailored dental braces and crowns as well as hearing aids and prosthetics. These were previously hand-made but are now becoming increasingly 3D printed (Lipson and Kurman 2013a: 33).

### 2.7.4 No lead time

Apart from enabling cost effective small batches having no requirement for re-tooling means that 3D printers have no lead time when it comes to manufacturing new products. A new product can be fabricated immediately after the previous one is finished. This allows for companies to manufacture on demand (Lipson and Kurman 2013a: 22).

This also allows for flexibility. If a manufacturer wants to change the design of the product in case, for example, there is a flaw in the original design, the production needs to be halted for only the time it take to change the digital design. The machine stays the same and only the instructions it receives from a computer are altered (Anderson 2012: 89).

## 2.8 Disadvantages of 3D printing compared to traditional manufacturing

Though additive manufacturing has some clear advantages over traditional manufacturing, there are severe limitations to it as well.

For one the actual production time of an average 3D printed object is significantly longer than that of a mass produced one. While it is likely that 3D printing technologies will become significantly faster over time, they will never reach the kind of production speeds as existing technologies such as plastic injection moulding. The fact of the matter is that the limitations of the physical reality, such as friction and viscosity, will not allow 3D printing to be as fast as, never mind faster than, plastic injection moulding. (Barnatt 2013: 205; Anderson 2012: 87-89)

Due to the lower production speed, the manufacturer of a mass produced item would have to be mad to move to additive manufacturing. If the company would want to keep up with the quantities of a competitor that uses plastic injection moulding, it would require not only a substantial number of the 3D printers but also technicians to operate them. Therefore, even if we assume that the cost of raw material were the same for both of the manufacturers, at higher output levels the average cost for the company utilising 3D printing is much higher than that of the competitor making it less profitable (Dawson et al. 2006: 54-57).

## 2.9 Challenges of 3D printing

Besides the disadvantage of never being as good in mass production as the current technologies, 3D printing faces some challenges going forward. Though these challenges at the moment limit the technology, solving them could lead to a significant advancement of 3D printing.

### 2.9.1 Materials

Apart from Fab@Home and a couple of models based on stereolitography, all the consumer level 3D printers use thermoplastics as their printing material. The current models are also limited in the number of materials they can use per print job; for the most part it is one (see appendix 1).

The cost of the materials that are available is an issue as well. According to Plasticker (2014), a German material exchange, the price of black or white ABS between 14$^{th}$ of December 2013 and 14$^{th}$ of February 2014 fluctuated between 1830 and 2030€/tonne or 0.183 and 0.203€/kg. Meanwhile the price of non-proprietary ABS filament for 3D printers is approximately 20€/kg (Amazon 2014; eBay 2014; MakerFarm 2014; 3D Prima 2014).

The cost of filament for consumer use could be cut significantly by using a plastic reclaimer such as The Filabot by Tyler McNaney. The Filabot allows the consumer to use waste plastic to make new filament for 3D printers. The invention consists of a grinder that grounds the plastic down, an extruded that melts the ground material and forces it through a nozzle creating standard 1.75mm or 3mm filament, and a spooling system that spools the ready filament once it has cooled (Barnatt 2013: 164-165).

Fabrics are a big challenge to additive manufacturing. Though there are some existing examples of clothes being 3D printed (Lipson & Kurman 2013: 184-185) It would seem inconceivable that with the current materials 3D printed clothes would become mainstream. As the technology progresses, however, 3D printed fabrics and subsequently clothing may become possible.

On professional level additive manufacturing technologies can actually increase the range of materials. The evolving multi-material 3D printing allows for the easy mixing and blending of several types of raw materials. These new composite materials could have novel, useful properties (Lipson & Kurman 2013a: 23). There are already several models of multi-material 3D printers available in the market. The Objet500 Connex3 by Stratasys is the world's first multi-material 3D printer that can also print in colour. The Connex3's prints can range from soft, rubber-like materials to hard plastic ones. The can be transparent or opaque and a single print can have up to 46 colours. This technology is obviously not available for average consumers as the machine with its material cabinet has a combined weight of over 500kg and a price tag of €240,000 (Stratasys 2014; 3ders 2014)

### 2.9.2 Active components

The current 3D printers of all level have the same limitation – they can only fabricate passive objects. Any circuitry, motors, or even LEDs have to be added separately. Neil Gershenfeld (2005: 101) calls this the final frontier in rapid prototyping.

Fabricating contemporary electrical systems with a 3D printer can be a near impossible task. Electrical wiring consists of conductive metals that are wrapped in non-conductive rubber or plastic. Trying to build wiring with additive manufacturing techniques is tricky as the melting temperatures of metals are much higher than those of plastics. The printed metal would simply burn the plastic (Lipson & Kurman 2013a: 271-272).

Printable materials that could solve the challenge of active systems, such as conductive plastics, have been developed and proved to work in laboratory conditions. Implementing these materials to form active, 3D printable systems will be the main challenge of additive manufacturing in the future.

### 2.9.3 Software and 3D Scanners

Though the actual printing of a design file on a 3D printer is not much different from printing a word document with a 2D printer, the actual designing of the product is not a simple task.

The design files are made using CAD (Computer Aided Design) programs. As is the case with programs like Adobe Photoshop, CAD programs require years of practice to master. An average consumer can just start using one of these programs and design their own object, sure, but the outcome will be considerably poorer than that of a professional designer.

To make the mass customisation of products possible Lipson and Kurman (2013a: 58-59) propose something called FabApps. These would be small applications, not unlike the apps readily available for your smartphone now. Instead of launching livid digital fowl towards some green swine, however, these apps would allow you to create a customised design file for a certain product. By limiting the number of functions the app has, the consumer can create a custom-made object effortlessly.

The hardships created by the design programs could be mitigated by another complementary technology – 3D scanners. There are already devices that allow their users to capture a 3D image of any object and import it to their computer. The captured 3D model can then be modified and printed out. 3D scanners allow their users to easily replicate existing items making them ideal for creating spare parts. Experts believe that future 3D printers come bundled with a 3D scanner, not unlike many of the current 2D printers (Anderson 2012: 84-86; Barnatt 2013: 210-211)

## 2.10 How could 3D printing affect retail?

There are several potential effects 3D printing could have on retail. If products could be printed on demand, the inventory of stores could be digitised. These products could be customised before printing and they would never go out of stock. The barriers to entry would be lowered significantly allowing even smaller businesses on the market of manufactured goods. Companies could sell their products online to be printed at home or in a printing bureau near the customer.

### 2.10.1 Digital inventory and print-on-demand manufacturing

Barnatt (2013: 14-16) predicts that by the end of the decade at least some retailers will install high-end 3D printers that will allow them to print products on demand. The stores could have a partly digitised inventory and the products could be customised before fabricating them.

What kind of products could then be in this digitised inventory? Kotler and Armstrong (2010: 250-264) divide consumer products into four categories: convenience products, shopping products, specialty products, and unsought products. As convenience products are sold en masse and have low price they are not well suited for print-on-demand manufacturing but will likely remain produced by traditional means due to reasons discussed in chapter 2.8. The products better suited for print-on-demand fall under the shopping and specialty product categories. However, even there not all products can be printed. As the fabrication of active components remains a challenge to additive manufacturing (see chapter 2.9.2), consumer electronics and appliances cannot be printed. As for the specialty goods, these are normally products with strong brand identity. Their buyers have a strong brand preference and loyalty and the products are sold in only a handful of outlets. Even if the fabrication of these specialty products on demand in stores were possible, it would seem inadvisable when considering the brand positioning.

When considering these factors the actual number of products that can actually exists in digital inventory becomes quite limited.

Barnatt clarifies later (2013: 205) that he neither believes that a store even two decades from now will print everything on demand. He places the focus of in-store printing on custom-made products and spare parts for existing products.

### 2.10.2 Lower barrier to entry

In traditional manufacturing industry the economies of scale create a barrier to entry for new interested companies. Since in any industry where economies of scale apply the long-run average cost curve slopes downwards, the average cost for the manufacturer will fall as the output rises. If another company was trying to enter the market, they would soon discover that with their output their average cost is much higher than that of the competitors that already existed in the market (Dawson et al. 2006: 58, 91).

As discussed in chapter 2.7.3, additive manufacturing does not fall victim to economies of scale allowing small or even single batch production. This lowers the barrier to entry significantly as the amount of initial capital is reduced.

A lower barrier to entry could bring large amounts of new companies to the market. As they will not have to invest upfront in inventory or tooling they can utilise a business practice known as scaling up from one. The would-be businesses could manufacture only a couple of products to test the market and slowly increase the produced quantities if there is demand (Lipson & Kurman 2013a: 57-58).

This does not, however, mean that everyone can simply design a product and start a business. The design programs do require extensive expertise. A good parallel could be drawn with HTML, a computer language with which websites can be written. Most people have access to a computer and therefore could start their own business making websites. The problem is the expertise and not the access. Instead people with the drive and talent to become designers will have easier access to the market (Lipson & Kurman 2013c).

### 2.10.3 Buy online, print at home or in a 3D printing bureau

Another application of 3D printing that could truly revolutionise retail is the possibility of buying products online and simply printing them at home. As downloading designs that can be printed at home is already an option, this type of retail is not only possible but also exists.

However, the current consumer level 3D printers, as discussed in chapter 2.9.1, are fairly limited in the materials that are available for printing. This combined with the relatively small print area limits the use of home 3D printers significantly.

Even if the kind of multi-material devices such as Objet500 Connex3 would become cheap enough for the average consumer to own, there are some physical realities to face. The raw materials for the printer would take up a lot of space. The Connex3 weighs 500kg and is the size of a chest freezer, hardly the kind of device that everyone would own.

This is why several experts believe that many of the 3D printed products that consumers buy online would actually be printed in 3D printing bureaus. Unlike the average consumer, the bureaus can have the latest technology and a much wider range of materials.

# 3 Interviews with retail professionals

Having identified the key questions regarding the issues based on the overview, the following research questions were formulated:

1. When will retail professionals expect consumer level 3D printers to be available in stores and how will they be perceived by the consumers?
2. How would the possibility for cost effective small batch manufacturing and mass customisation affect retail?
3. How could additive manufacturing technologies be utilised in retailers' internal processes?
4. How will 3D printing affect retail?

## 3.1 Methodology

Due to the current low adoption rate of additive manufacturing technologies, the research questions above were pursued by the means of a qualitative rather than quantitative study, as this approach was estimated to produce better data.

The form of data collection chosen was a series of interviews with retail professionals. These professionals work in the purchasing and merchandise operations departments of Stockmann's department store division. All the interviewees were chosen within Stockmann's organisation because the author has access there.

Questionnaires were created based on the research questions, but were drafted for each interviewee individually and consisted of both questions that were asked of everyone and individual questions related to each interviewee's area of expertise. The interviews were semi-structured, which allowed for additional questions when deemed necessary to insure fullest possible responses from the interviewees.

Stockmann is a public limited company established in 1862. In 2013 the group's revenue was €2,037 million. The department store division has 16 department stores in four countries (Finland, Russia, Estonia, and Latvia) and in 2013 made €1,232 million in revenue (Stockmann 2014).

The interviewees are: Harri Saarto, Chain Manager in food purchasing; Piia Inkinen, Buyer in home merchandise area; Jari Latva-Karjanmaa, Product Group Manager in electronics purchasing; and Katja Binkley, Supply Chain Specialist. The dates and durations of the interviews are listed on table 1. The full interviews are available in attachments 2-5.

| Name | Professional title | Duration of interview | Date of interview |
|---|---|---|---|
| Piia Inkinen | Buyer | 24 min | 15 April 2014 |
| Jari Latva-Karjanmaa | Product Group Manager | 42 min | 16 April 2014 |
| Katja Binkley | Supply Chain Specialist | 31 min | 17 April 2014 |
| Harri Saarto | Chain Manager | 19 min | 17 April 2014 |

Table 1: Description of the qualitative research sample

This chapter is divided into subchapters based on the research questions.

## 3.2 Consumer level 3D printers

Stockmann has been a frontrunner in the consumer level 3D printers in Finland as they have had one model on sale at the Crazy Days campaign in autumn 2013. Those sold around 5 units. According to Latva-Karjanmaa only one other retailer in Finland, Verkkokauppa.com, has had 3D printers in their selection, though he adds that there might be some smaller retailers he is not aware of.

Latva-Karjanmaa believes that consumer level 3D printers will be available in stores' normal selection starting in 2015 and by 2020 most electronics retailers will sell them. He states that the consumer devices need to become more user-friendly and the materials more versatile before 3D printers are more prominently sold by retailers. There is also an issue with branding as the manufacturers of 3D printers are not known by the consumer.

When asked whether there is a real need for a device like a 3D printer, Latva-Karjanmaa says no for the most part. At the current level he feels that consumer level 3D printers will remain a niche product that the majority will perceive as a toy. He does admit, though, that even at the moment there are people who might have a legitimate need for a 3D printer and mentions model builders and DIY hobbyists as an example. Harri Saarto thinks along the same lines. He questions the need for a private individual to have a 3D printer at home. He grants that the idea of being able to manufacture objects at home is intriguing but thinks that the technology is still too immature to be of any real use.

As the 3D printers get better and faster over time Latva-Karjanmaa believes that the consumer perception will shift from toy to status symbol. He says that within the next couple of decades the numbers of 3D printers at home have significantly increased. However, within the next decade he estimates the adoption rate to be less than 10% of homes. Saarto predicts the adoption rate to be modest as well. He questions the necessity of owning a personal 3D printer. In his opinion the use would be too infrequent to have it occupying space.

Saarto finds it extremely improbable that food printing will become popular within our lifetime. Though there might be some applications for professional athletes and medical purposes, Saarto does not see them catching on with the average consumer.

## 3.3 Small batch manufacturing and mass customisation

At the moment Stockmann does not design the products of their store brands in the home merchandise area themselves. Inkinen says that this is due to the relatively low volume of sales. The store brands are supposed to have a competitive pricing and the unit cost for proprietary designs would be too high.

If small batch manufacturing would become a viable option, Inkinen believes that at least Stockmann would design more of their own products. She points out that the fashion merchandise areas already design their house brands. Unique store brand designs could help Stockmann differentiate and stay ahead of emerging trends.

Binkley sees small batch manufacturing bringing new companies to the market. The reduced requirements of initial capital and expertise would help smaller companies to the market.

All interviewees find mass customisation an interesting prospect. Inkinen points out that customisation is very trendy at the moment and Latva-Karjanmaa can even point to products such as phone and tablet covers where there would be a good business opportunity once the speed and quality are at an appropriate level. He believes that in the future retailers might have the mass produced goods on the shelf, but at the same time allow consumers to customise the standard design and print a unique, tailored product.

Saarto, however, reminds that not all products will benefit from customisation and that convenience goods will remain largely mass produced.

## 3.4 Use of 3D printing in retail's internal processes

When asked whether or not 3D printing could be used in Stockmann's internal processes Inkinen points out that at the moment selecting products for her merchandise group is a slow process. New products are sought out in trade shows and samples requested. It takes usually 1-2 weeks before the samples arrive. The most suitable candidates are then chosen and orders placed to the manufacturer.

Being able to print the samples in the office could significantly reduce the time it takes to choose new products. If the manufacturers' selections could be viewed online and samples printed in the office in the matter of a few hours, it would allow the purchasing department to compare the products of more manufacturers. It would also allow more people to have input in the selections throughout the process. At the moment only buyers visit the trade fairs and have actually seen the whole range of available choices. Involving the planning organisation and assistants could provide invaluable insight that could help with assortment decisions.

Latva-Karjanmaa does not see 3D printing to have a significant role in the internal operations of a retail company. He mentions that at least in Stockmann there are internal policies to reduce waste. Frivolous 3D printing would go against those policies. He mentions 3D displays as an alternative. They would allow for better reviewing of digital samples while reducing the necessity of actually printing them out as physical objects.

Another internal process where 3D printing technology could be an asset is catalogue photoshoots. Binkley knows about a couple of incidences where a product that was supposed to be in the monthly loyal customer catalogue was forced to be left out as there was no sample available in the time of the catalogue photoshoot.

### 3.5 3D printing’s effect on retail

None of the interviewees see 3D printing as a threat to traditional retail. Binkley mentions the speculations of the late 90s when many believed that ecommerce would take over almost all retail. The much hyped shift to online retail did not come to pass and instead lead to the dot-com bubble.

Latva-Karjanmaa points out that there are some merchandise areas where 3D printing might have significance but does not believe it to be true in nearly all retail. In his own merchandise area, electronics, Latva-Karjanmaa states that 3D printing will not have a negative impact on sales. As almost all his products have active components they cannot be reproduced at home. On the other hand the sales of 3D printers and filaments could have a positive effect on the bottom line but as Latva-Karjanmaa estimates the sales to be quite low for quite some time even this will not be significant.

Even Inkinen, whose merchandise area could directly be affected by the increase of at home 3D printing, sees more opportunities than threats when it comes to the technology. She feels that the increasing possibilities for customisation, the possibility of own designs, and the lower barriers to entry for small businesses will increase the selection retailers can have in stores. She does not see consumer level 3D printers becoming common enough to pose any real threat to retail in at least the next decade.

The most useful application of 3D printing from the consumer perspective will be the ability of manufacturing objects you cannot buy. Being able to create spare parts for the products you already own could increase the lifespan of mass produced goods. Binkley mentions an example in her own life – a baby carriage with a broken axle support. It is only a small plastic part but it is critical for the proper functionality of the entire carriage. Her husband tried to repair it with glue but that did not work and as a spare part is not easily available they likely need to buy a whole new carriage.

Saarto urges caution when it comes to spare parts, though. A plastic replacement part for a roller curtain should be safe enough, but when it comes to vintage cars an amateur should not even try to make a spare part themselves. A part that is not properly tested might break under the forces it is subjected to, leading to a catastrophic failure and loss of life.

When asked about the kind of retailers that will adopt 3D printing first, Latva-Karjanmaa mentions 3D printing bureaus as a possible emerging business model. Binkley thinks among the same lines and suggests that existing copy shops will likely broaden their operations that way. Other possible retailers would be specialty stores focused on consumer electronics, scale model building, and photography. Latva-Karjanmaa also mentions auto mechanics and in general businesses that often require small, sometimes customised parts. When it comes to food production Saarto believes that some bakeries or patisseries will, if they have not already, adopt 3D printing in their processes. As the technology to 3D print, for example, chocolate already exists the pastry chefs could incorporate 3D printed components in their custom made works.

## 4 Results and analysis

When contrasting the opinions of the experts with those of the retail professionals we find that there is a remarkable correlation between the two. Both believe that consumer level 3D printers will be available at electronics stores within a couple of years, but the adoption will be slow as the first models on the shelf will likely be perceived either as luxury goods, toys, or special tools for a niche market.

The use of consumer level devices will be limited primarily due to the materials available for printing, the inability to create active components and tricky design software.

Though Hod Lipson sees that food printing will be the "killer app" that will bring 3D printing to every home, the opinions of both Christopher Barnatt and Harri Saarto make that seem unlikely.

Whether 3D printing technologies will develop to the point where every home has one, or as Lipson predicts several, is difficult to say at this time. It would seem likely that as the technologies get better, the price goes down, and consumers have a chance to try the machines themselves more and more consumers would adopt 3D printing technologies. It would, however, seem equally likely that not everyone will own a 3D printer. Due to the sheer size that a multi-material 3D printer will inevitably have, it is likely that most of 3D printing will remain in professional hands.

3D printing will allow more small businesses to enter the market of manufactured goods. This will increase the selection of goods available for consumers. The number of these small businesses will, however, be more moderate than some pundits would have us believe. Designing at a professional level is difficult enough to ensure that. If the manufacturing of small batches becomes economically viable, retailers would also have the ability to design their own store brands.

Additive manufacturing will enable companies to tailor their products more to the preferences of the consumer. As the retail professionals, too, recognise the market for mass customised goods, it is likely that in the future many of the products available in stores can be customised. This will, however, not be true with every retailer as discount stores will continue to focus on mass produced goods with low costs.

3D printing cannot replace mass production in the foreseeable future. The economic reality is that mass produced items are cheaper to produce. Most of convenience goods will remain mass produced, as customers are likely to prefer lower prices over customisation.

Digitising inventory and printing products on demand would require 3D printers that can produce goods in a matter of minutes, preferably seconds, and not hours as the current printers do. Even then the volume would soon become so high that generic goods will be cheaper to buy from a mass producer.

When it comes to internal processes of retailers, 3D printing could have some viable applications. These applications are likely to resemble the main use of current 3D printers – making prototypes. These could be product samples or items for catalogue photoshoots.

Apart from mass customisation, the most promising use for 3D printing, according to some experts and retail professionals, is the production of custom-made one off items and spare parts for other goods. As the spare parts that used to be unavailable for average consumer will be within their reach, the life span of many consumer goods could theoretically expand. Whether a new culture of repairing existing goods emerges, never mind replaces the current disposable culture, remains to be seen.

While some experts say that 3D printing will revolutionise retail, others are more conservative. Retailers themselves consider the technology a possible new sales channel, but not threatening the industry; comparable how ecommerce has become a part of most retailers operations. Provided the technology becomes widely spread and commonplace retail will likely be re-shaped like the video gaming industry, where the same product is available via multiple channels.

## 5 Conclusion

Consumer level 3D printers will shortly be available in stores and within the decade most retailers will have them at hand. Due to their limitations they will have a slow adoption rate and might never reach full market penetration.

Apart from selling the actual devices and their filament, 3D printing, however will not have a significant impact on retail. Mass produced goods will, in the foreseeable future, still be bought from traditional retailers (or perhaps their online stores).

3D printing will ease the market access for small manufacturers by lowering the barriers to entry, leading perhaps to a wider range of products on the market. By the same token retailers will be able to design and manufacture their own store brands that are proprietary and low volume.

Mass customisation will become increasingly possible as 3D printing technology progresses. Retailers will initially offer only a few products to be customised, smartphone covers might be a good example, but the number of customisable products will grow as the idea of mass customisation gains traction. Retailers will, however, keep offering generic goods as well and in the case of discount stores the customisation will be minimal.

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# Appendices

## Appendix 1: Closer examination of the categories of 3D printing

### Material extrusion

Nearly all consumer level 3D printers are based on material extrusion technology. Although this technology allows printing in a variety of materials, the most commonly used are thermoplastics.

Most of the commercially available 3D printers use thermoplastic extrusion, a sub category of material extrusion, as their modus operandi. As there is no real consensus regarding the naming of the process and some companies having trademarked their label for it, it is sometimes referred to as Fused Deposition Modelling (FDM), Plastic Jet Printing (PJP), or Fused Filament Fabrication (FFF). These printers feed a spool of raw material, known as filament, through a computer controlled print head nozzle. The nozzle heats the filament to a temperature between 150°C and 250°C which melts the raw material enabling the printing; therefore the print head is sometimes called the hot-end.

The first layer of filament is extruded on what is known as the printer’s build platform or bed, a smooth, flat, horizontal and occasionally heated surface below the print head (Barnatt 2013: 27-29). Some printers keep the build platform stationary at this point and move the print head on both the x- and y-axis while others move the print head on one axis and the build platform on another. Next, depending on the printer being used, either the build platform lowers or the print head raises one notch and the following layer is extruded on top of the previous and so on.

Currently the thermoplastic extruder printers use mainly two types of thermoplastics – acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). Both filaments are available in several colours in standard spools with diameter of either 3mm or 1.75mm.

ABS is the cheaper of the two. It is a plastic polymer widely used in injection moulding. It is, for example, the material of which Lego®-bricks are made. ABS is extruded in temperatures between 215°C - 250°C and the heating creates mild, generally tolerable fumes that can be dangerous to sensitive people and certain pets. It is recommendable to use a heated bed when printing with ABS as the print might otherwise warp while cooling down. This, however, is not a requirement and smaller prints should do just fine even without one. ABS can be sanded and smoothed to a glass-like shine (Baumgarner 2013). There is also ABSi, a variant that can be used in food production and medical applications, as it can be sterilised.

The fact that 3D printers can use a material as common as ABS is very significant in the proliferation of the technology. A manufacturer seeking to produce a small batch of a good might find it cheaper to use 3D printing than plastic injection moulding where the costs for tooling and the mould itself can be quite high.

The other common thermoplastic, organic PLA, is typically made from agricultural produce, for example corn or potato starch, or sugar cane. It is extruded in temperatures between 160°C - 220°C and instead of toxic fumes it creates a faint aroma of sweet, toasted corn when heated (Barnatt 2013: 31). Due to its biodegradability, eco friendliness, and non-toxicity PLA is the filament of choice of many 3D printing hobbyists. As with ABS, using a heated bed while printing with PLA will prevent the print from warping. Standard PLA is stiffer than ABS. There is, however, a flexible variant of PLA that can produce objects that are squishy.

Some printers with multiple extruders also use PVA, polyvinyl alcohol, to create support for the actual filament. This enables these 3D printers to create overhangs and similar structures, which can be nearly impossible to print otherwise. As PVA is completely water soluble, it can simply be rinsed off of the final work (Baumgarner 2013).

As mentioned, 3D printers utilising material extrusion technology are, however, not limited to thermoplastics. Almost any material that is in the form of a liquid, paste or powder can be extruded from a print nozzle. Materials used in 3D printing already vary from edible goods, such as cookie dough and chocolate, to concrete and even living cells. The technology has therefore the potential to revolutionise food production, construction and even medical research. The applications can range from small, everyday household appliances to massive construction machinery. (Lipson & Kurman 2013a: 68-70)

Even more traditional materials, such as wood, metal and ceramics can be used in material extrusion. There is a filament called "LAYWOO-3D" which is a composite of wood fibres and a polymer binder. It can be printed even with your standard consumer 3D printer and will result in a product that feels and smells like wood. The finished product can even be sanded or otherwise worked just like wood (Barnatt 2013: 41). Metal and ceramics are a bit trickier. Though a consumer level 3D printer can extrude a gel mixed with metal powder or a ceramic, these materials require a kiln to solidify and take their final form. Not only can this warp the end product, it also makes these materials unavailable for an average consumer who, most likely, does not have an easy access to a kiln (Lipson & Kurman 2013a: 83-84).

While most current consumer level 3D printers have a single print head, it is possible to have multiple nozzles in one device. These can all extrude a different raw material and create objects with compositions unachievable by traditional means. Similarly there are experimental 3D printers that can mix several materials in their print nozzle. The aim here, generally, is to mix different colour thermoplastics in order to create objects in full colour, not unlike the contemporary two dimensional colour printers. (Barnatt 2013: 37).

Photopolymerization

3D printers employing photopolymerization use a light source, most commonly a laser, to cure liquid photopolymer into a solid object. Photopolymerization encompasses such technologies as stereolitography, DLP projection, and two-photon polymerization.

As previously stated stereolitography was the first 3D printing technology invented. Stereolitographic 3D printers - also known as Stereolitographic Apparatus or SLAs – sweep a laser over a pool of liquid photopolymer tracing the wanted shape of the layer. After one layer is complete the moveable table holding the object being printed lowers or raises a fraction of a millimetre (depending whether the laser is being aimed at the surface or the bottom of the tank), the liquid photopolymer envelops the object, and the laser starts outlining the next level (Lipson & Kurman 2013a: 73-74).

DLP (digital light processing) projection is another way cure photopolymers. Here a projector is used to cast an image of the wanted layer shape onto the photopolymer thus selectively solidifying it. The print platform will then once again move and the next layer is cured and so on (Barnatt 2013: 47-50)

In March 2012 Don Fujiwara posted an article on *3DPrinterHub.com* about a remarkable recent technology called two-photon polymerization, or 2PP. On the surface 2PP is a lot like stereolitography, layers of liquid resin are cured with a laser, but it is vastly superior in terms of speed and precision. Whereas stereolitography has a build speed of some millimetres per second and accuracy of tens of micrometres at best, 2PP can reach a build speed of 5 metres per second and can build at a scale of <100 nanometres laterally. Therefore 2PP may well in future have several applications not only in nanotechnology but also in the making of larger objects.

The final technology that utilizes photopolymers is known as material jetting (once again the technology might have other labels, for example polyjet, PolyJet Matrix, multi jet modelling or inkjet photopolymer, depending on the manufacturer of the printer in question). Here the photopolymer resin is sprayed from an inkjet style nozzle into the desired layer shape. The printed layer is cured with UV light before the next one is applied and so on. Unlike the other 3D printers in its category, which use a vat of liquid resin, material jetting printers can use several materials in a single print job (Barnatt 2013: 53-54).

Though there are some consumer level 3D printers that use photopolymerization, it is mainly a technology for professional use. There are many reasons for this. Firstly the fumes released by uncured photopolymers can be toxic. Secondly the final products created with photopolymerization usually require some additional work before they can be used. The print must be rinsed to get rid of the excess resin, and sometimes requires even further curing in an ultraviolet oven. Finally there is the cost. The cheapest consumer level stereolitographic 3D printers cost around €2,500 whereas the cheapest FFF printers can be acquired for €300.

Photopolymerization has its advantages over material extrusion, mainly its resolution. Objects created with this technology have greatly smoother surface than, for example, items made of extruded thermoplastic. Of course, the layer thickness can be increased which on one hand will result in poorer resolution and uneven finish but on the other will increase the print speed.

There is already a reasonably wide assortment of photopolymers in the market. The current selection contains both flexible and rigid materials in a variety of clear and opaque colours and the quality and range keep increasing as materials technology progresses (Lipson & Kurman 2013a: 73-74).

Granular materials binding

The final category of 3D printers consists of technologies that affix powdered material either with a binder or by fusing it together with heat. The material can be, for example, a plastic, a metal, ceramics or even glass.

In binder jetting an inkjet-like nozzle traces the shape on to the surface of a thin layer of the powdered material spraying a binder. After the first layer is finished the print platform, which in this context is often referred to as powder bed, lowers and a roller spreads more powder from the adjacent powder reservoir onto the work in process. The advantage of this type of process is that the excess powder will end up supporting the print, making it possible to create overhangs and other shapes that can be tricky to print with the other technologies. On the other hand creating a hollow, closed object is impossible as the excess powder will be trapped inside the print.

An additional benefit of binder jetting is that it is capable of printing in full colour. This is achieved quite simply by adding colour to the adhesive. The standard combination of cyan, magenta, yellow and black (known as the CMYK colour model) which is used in 2D colour printers can be easily fitted to a binder jet printer enabling it to produce a range of over 4 billion different shades.

After the print is completed a binder jet printer lets the final work set within the powder bed to let the adhesive harden. The loose powder is then removed; some 3D printers do this automatically. Whereas a plastic object does not necessarily require any more work, a metal, ceramic or glass object does. These need to be fired in a kiln to solidify the material (Barnatt 2013: 54-62).

Laser sintering is very similar to binder jetting. This technology uses a laser instead of an adhesive to fuse the granules together. As the laser has traced out the desired shape the print bed is lowered and a layer of fresh powder is rolled out. Laser sintering can produce metal objects that are ready for use and do not need to be fired in a kiln as the metal powder has already been fused together and not just affixed with an adhesive (Lipson & Kurman 2013a: 75).

Directed energy deposition or laser powder forming (LPF) uses a laser to heat a small area and aims a stream of metal powder at it to form a melt pool. The computer controlled deposition system, a large mechanical multi axis arm, guides the melt pool and deposits the material where needed. As this technology does not use a powder bed, the print can be quite large. In addition to creating whole new objects, LPF can be used to add material to existing objects and repair them (Thre3D 2014).

At the moment granular materials binding is for professional use only as none of the consumer level 3D printers on the market uses these technologies.

Appendix 2: Interview with Piia Inkinen, Buyer

The interview was conducted in Finnish and was translated by the author.

*What is the current process of purchasing Stockmann's own brands?*

First the purchasing department assesses the assortment and checks what type of goods are needed. Then the goods are searched in trade shows and samples requested. The selected products are ordered from manufacturers in the Orient, mainly China.

*Does Stockmann design any of their own brand products?*

There is some design done in clothing departments, but not elsewhere.

*Why is that?*

It is simply not cost-effective. The mould would cost way too much considering how small the production quantities would be. The Stockmann brands are supposed to have competitive pricing.

*How does Stockmann receive product samples from manufacturers and how long does it take?*

They are delivered by UPS. It takes 1-2 weeks on average.

*Does Stockmann also receive the designs in a digital form (CAD etc.)?*

No. We just receive physical samples.

*Would it make a difference in the purchasing process if a sample of the product could be printed out right away?*

It would. Selecting the promising products online and printing them out would speed up the selection process making it easier to compare the products of more manufacturers.

It would also allow the whole purchasing team to see the samples of all products. At the moment only the buyers who visit the trade shows actually see the products.

Oh, it could also reduce travelling cost as the need to go to trade shows would decrease.

*If there was no tooling or mould costs in manufacturing allowing smaller batches to be produced do you think Stockmann would design their own products?*

I am sure it would. We already design clothes, so why not design other products too. It would help us differentiate and stay ahead of emerging trends.

*Do you think that there is a market for mass customised goods for your merchandise group?*

Yes I do. Customisation is really trendy. Mass customisation could really catch on if the price is right.

*How do you expect the manufacturing industry to develop in the near future? Will rising labour and energy costs lead to more manufacturing in the West?*

In the case of some products, yes it will. Because of the concerns you mentioned as well as the antidumping laws. The costs are going to rise.

But it is not going to be that everything will be made in the west. I would expect the manufacturing to even out geographically.

There are already examples. Mostly they are in high-end brands.

*What would you expect the adoption rate of home 3D printers to be before Stockmann begins to sell home-printable goods?*

It has to be at least 10% of the consumers. Then again, Stockmann might not be an early adopter in this matter.

*If some of Stockmann's inventory was digitised and printed to order do you think it would be printed by Stockmann or by a third party supplier?*

It would have to be a third party. I don't see that Stockmann would go into manufacturing.

*What type of retailers would you expect to adopt 3D printing first?*

Likely it will be the smaller ones.

*How would you describe Stockmann when it comes to innovation?*

We can sometimes act very fast. When we see something that works in other countries we are quick to take it to our selection.

*Do you expect 3D printing to have an impact on retail? What kind?*

If it develops further it will. Digital inventory will allow retailers to expand selection. The number of suppliers could increase if the small batch runs could be cost effective. There would be less stock pressure and better inventory turnover if the warehouse was restocked by print-to-order basis. It would increase customisation as well.

*How would you estimate the impact of at home 3D printing on your specific merchandise group?*

It might eventually have an impact. At the moment I do not see the technology getting traction among the consumers that rapidly. We are talking about a decade before this becomes an issue.

*How would you describe your knowledge of 3D printing?*

I am aware that it exists, but I have not seen it personally.

Appendix 3: Interview with Jari Latva-Karjanmaa, Product Group Manager

The interview was conducted in Finnish and was translated by the author.

*How many units of the Cube 3D printer were sold in the Crazy Days campaign in autumn 2013?*

There was something around 4 or 5 sold. The product did get plenty of interest, though. It was being demonstrated in the Helsinki department store and plenty of people stayed to watch it in operation.

*To your knowledge, has any other retailer in Finland sold 3D printers?*

Verkkokauppa.com has at least had them in selection. There might also be some small online retailers.

*Gartner expects that by 2015 seven of the 50 largest retailers will sell 3D printers. When do you think that Stockmann will have 3D printers and filaments in their normal selection? Will Stockmann be a frontrunner or will other retailers precede them?*

Stockmann still actually has a couple of the 3D printers from the autumn 2013 Crazy Days campaign left. They are being sold in our online store.

But I believe that we will likely have them in selection in 2015 as well. We will probably be one of the first to have them in normal selection. Most electronics retailers will have them in selection by 2020.

*What needs to happen to consumer level 3D printers before they are sold by retailers?*

The quality and versatility of the printed material needs to get better. At the moment most of the prints are knick-knacks made of semi-soft plastics.

The printers also need to become more user-friendly. They need to work right out-of-the-box.

The main problem is not the 3D printers but the companies that sell them. The companies have always sold to industrial clients so the consumers do not know the companies and the companies do not know the consumers.

*Do you think that there is a need for a device such as a 3D printer?*

Currently I think it is a niche product.

*How do you think consumers will perceive 3D printers; as a tool, as a luxury item, as a toy, or as an everyday appliance?*

Initially more like a toy or maybe a tool for certain hobbyists. Maybe something for DIY enthusiasts or people who build scale models as a hobby?

*Do you think this perception will change over time?*

Yes, I am sure it will. As the 3D printers become nicer and faster they become a status symbol.

*Do you think that someday almost all homes will have a 3D printer?*

I do not think that every home will one, no. But then again who knows. I do say that their numbers will significantly increase within the next couple of decades. But in ten years from now I think you will find one in less than 10% of homes.

Then again people are really bad at estimating how technology will develop over time. If you ask someone about the level technology 2 years from now they say it will be pretty much the same. When you ask about how it will be in 20 years suddenly they picture flying cars. The truth is that some technologies can develop enormously in just a couple of years, whereas we will probably not have flying cars even 20 years from now.

*To what extent would you expect the average consumer to design and print their own products? Would this be a threat to retail?*

It will take at least 10-20 years before we get to a point where this is going to be an issue. And even then I think that people will print things like wall plugs. If the consumer level 3D printers achieve factory quality they might pose a risk. But even then I think people would only print stuff they cannot buy in stores, like parts for a vintage car from the 50s.

*Do you think that there is a market for mass customised goods for your merchandise group?*

There is a market for customised smart phone and tables cases. I think it would be a good business opportunity once the speed and quality are at an appropriate level.

*How do you expect the manufacturing industry to develop in the near future? Will rising labour and energy costs lead to more manufacturing in the West?*

The industry will likely move away from china to some extent but it will not come back to the West in great numbers. More likely they will find new regions with cheap labour, likely in Africa.

*As 3D printing has no tooling or mould making cost, it allows for smaller batches to be produced. How do you think this will affect retail?*

It would be ideal for retail to be able to do that. There would be greater stock turnover and less inventory pressure. It will not happen anytime soon, though. At the moment the unit cost would be way too high.

*Which ones of Stockmann's processes do you think could utilise 3D printing?*

Not many of them. There are corporate policies in place to reduce waste. This means we're moving towards a paperless office and even have to cut down on samples. 3D printing might go against that. Also there are other emerging technologies, such as, 3D displays that could reduce the need to bring digital samples to the physical world.

*What would you expect the adoption rate of home 3D printers to be before Stockmann begins to sell home-printable goods? What would it have to be for smaller retailers to enter?*

Not actually that high. I think 5% should do it. Smaller retailers might enter the market even sooner than that.

*If some of Stockmann's inventory was digitised and printed to order do you think it would be printed by Stockmann or by a third party supplier?*

Stockmann might actually do the printing themselves. But we do at the moment have contracts with third parties to print photo albums for our clients. It will all come down to the deals we can get from outside manufacturers.

But the idea of digital inventory is intriguing. We could have a couple of the factory made products on display and if the customer did not like them they could simply customise the design and print the product.

*What type of retailers would you expect to adopt 3D printing first?*

Speciality stores that focus on electronics. Also stores for model builders. Probably car mechanics will have interest. Basically, any retailer that deals with the kind of small parts that you could print out with a 3D printer will at least have interest. There might even be an emerging market for stores that specialise in 3D printing services.

*How would you describe Stockmann when it comes to innovation?*

Usually we are in the forefront of adopting new innovations if we see potential in the market. A good example would be mobile phones. We were one of the first stores to sell them in Finland and at the time they were really expensive.

*Do you expect 3D printing to have an impact on retail? What kind?*

In the long run it will have some significance in certain merchandise areas. In my own area [electronics; author's note] it will not have much impact – apart from the fact that we will be selling the devices and print materials. It will not cannibalise sales away from retail, but it might become a new channel for retail. It will increase the customisation of products.

There is a risk that one giant corporation will take over the online print-at-home market. Compare it to something like Amazon that has a significant share of all online retail.

I would compare it to videogames where the digital age has increased the number of retail channels. It used to be that you could only buy the physical copy of the game disc from stores. Nowadays you can buy the physical copy, buy a code from the store with which you can download the game, or even buy and download the game online. 3D printing could allow the same kind of thing to physical objects.

It could also help to bring new products to the market sooner. As an example there is this one woman company. The owner had the idea of designing an iPad holder that works like a kitchen drawer. It took her two years to get to a point where she had working prototype. If she had had access to a 3D printer, she would probably have gotten there faster.

*How would you describe your knowledge of 3D printing?*

I have seen a 3D printer and what kind of products it can fabricate. I have read about them in the papers. And I know someone who built his own 3D printer from parts.

Appendix 4: Interview with Katja Binkley, Supply Chain Specialist

The interview was conducted in Finnish and was translated by the author.

*How much logistics and warehousing costs does a good accrue on average?*

The cost of logistics and warehousing is a bit less than 10% on average. The cost of logistics of sales is less than 10%. I would say between 8% and 9%.

*How do you expect the manufacturing industry to develop in the near future? Will rising labour and energy costs lead to more manufacturing in the West?*

Yes it will. The cost of transportation is getting higher and it is sparking what is called "nearshoring" which means bringing the production closer to the customer.

This is especially true with high-end products. You usually need a bit more skilled labour to manufacture high-end and that is more readily available in the West.

The mass manufacturing will remain in Asia, though.

*Is there a viable threat of rising raw material costs?*

Not that I am aware, no. There is, of course, fluctuation in the prices but that is normal.

*Is there pressure to reduce waste in manufacturing?*

Yes there is. It will be a huge trend. As people become more environment aware it will be used more and more with communication to customers and stakeholder groups. It will be a great marketing tool.

*As 3D printing has no tooling or mould making cost, it allows for smaller batches to be produced. How do you think this will affect retail?*

It will have an effect. It lowers the barrier for entry for smaller businesses because it lowers the initial capital required. There would be less risk involved and the companies could manage it better. It reduces the need to have expertise on manufacturing. There have even been speculations that small batch production could be Finland's next Nokia.

*The production of niche products and mass customisation could theoretically increase the selection of one-off items and unique products. Do you think retailers would appreciate this or prefer mass produced goods?*

It depends on your customer segment. Department stores and discount stores will keep focusing on mass produced goods. However, specialty stores will probably appreciate it very much. It will help them differentiate.

*Which ones of Stockmann's processes do you think could utilise 3D printing?*

We sometimes have problems getting samples of the products in time for the catalogue shooting. Since the catalogues are made sometimes weeks before the product is in the country, it could really help our processes if we could make a replica of it for the photoshoot.

*What would you expect the adoption rate of home 3D printers to be before Stockmann begins to sell home-printable goods? What would it have to be for smaller retailers to enter?*

For Stockmann I think it would be at least 10% of the Finnish market. A smaller retailer could enter with a lower adoption rate too, especially if they are entering the global market.

*If some of Stockmann's inventory was digitised and printed to order do you think it would be printed by Stockmann or by a third party supplier?*

I do not see why we could not have our own production. It would have to be a very limited part of the inventory, though. Making everything would be too expensive.

*What type of retailers would you expect to adopt 3D printing first?*

Among the first would be stores like that [Binkley points out the window at Kopioniini oy, a copy shop across the street; author's note]. Also photography stores would likely adopt the technology quite soon. Then there would be the electronics stores and to some extent hobby stores.

*How would you describe Stockmann when it comes to innovation?*

We are usually an early adopter or at least in the early majority.

For example our Premier-magazine always features upcoming trends.

*Do you expect 3D printing to have an impact on retail? What kind?*

I see its main use being the manufacturing of spare parts for products. For printing something that you cannot buy otherwise. This could increase the lifespan of consumer goods, if you could simply replace some small part instead of buying a whole new product. We have a baby carriage at home. One of the small plastic parts on it that hold the axles in place is broken. My husband tried to glue it back together but that did not work. If we could easily create a new part we would not have to buy a whole new carriage.

In any case I cannot see it as a threat to traditional retail stores. There used to be talk that by now most of retail would have gone online. This did not come to pass. In fact the hype caused the dot-com bubble in the early 2000s. Retail has now adopted ecommerce and the companies use it as another sales channel. This will happen with 3D printing as well.

People want to actually see the product themselves before making a purchase decision. Buying, for example, clothes online is really difficult because you cannot try them on before paying for them. The clothes you can return, but how would you return something you printed at home?

*How would you describe your knowledge of 3D printing?*

I have heard about it and read several articles about it. It has been increasingly featured in papers. I also know someone who has access to a 3D printer and uses it frequently professionally.

Appendix 5: Interview with Harri Saarto, Chain Manager

The interview was conducted in Finnish and was translated by the author.

*Do you think that food printing will become popular among consumers?*

I cannot see that happening in our lifetime. It would take at least 50 years. There might be some applications for 3D printed food when it comes to professional athletes or perhaps medicine.

I know that scientists have been able to synthesise meat and it could be printed, but that is not going to be cost effective for a long time.

Also food is more than just nutrients. It needs to look good. I cannot imagine a machine printing out a salad any time soon. Not unless the technology suddenly leaps to Star Trek level. If you just print out nutrients you will end up with some grey gruel.

You could probably have some kind of food cartridges that can be used to bake a cake or muffins. But then again you could just mix the ingredients yourself or use cake mixes that are readily available in stores. I do not see a 3D printer adding value to the process.

*Do you think that Stockmann/retailers will go into printing foods to order using the kind of technologies that are already available such as printing chocolates?*

I am sure that professional bakeries and patisseries will and some probably already have. Stockmann might also get involved at some point if the quality and price were in order.

*Do you think that there is a need for a device such as a 3D printer?*

The idea of manufacturing stuff at home is really interesting, but the problem is what you are going to print. I know my house has a limit on how many plastic elephants and giraffes there can be.

I think that people who are going to buy a 3D printer in the next couple of years are more interested in the printer itself than what it can do.

*How do you think consumers will perceive 3D printers; as a tool, as a luxury item, as a toy, or as an everyday appliance?*

It is going to be perceived either a specialised tool or then just a toy. It all depends how it is pitched to the public. I cannot see it as an everyday appliance. In the long run, what are you going to print? Apart from groceries, people do not buy stuff daily so why would they print stuff daily either.

*Do you think this perception will change over time?*

If the technology develops enough it might. But even then I do not think that everyone will have one at home. You would use it around 10 to 20 times a year and the rest of the time it would just occupy space. Besides, even if the technology develops to a point where you can print with multiple materials at home, it would only mean that the machine would take up even more space because of the material storages.

*How do you expect the manufacturing industry to develop in the near future? Will rising labour and energy costs lead to more manufacturing in the west?*

Some of the manufacturing will move back to the west. It went to Asia in the first place because it created cost-savings once those are gone there is no reason to stay. It makes always more sense to manufacture near the customer. It saves you logistics cost and shortens your lead time.

*As 3D printing has no tooling or mould making cost, it allows for smaller batches to be produced. How do you think this will affect retail?*

It might increase customisation. If you can drive the cost low enough, it might even become significant.

*Do you think that there is a market for mass customised goods?*

There is for some vanity products yes. But you have to remember that the customised products will always cost more than generic, mass produced ones. An average consumer cannot afford to buy everything customised, not to mention have the time and motivation to do the actual customisation. Convenience goods will remain mostly mass produced.

*How would you describe Stockmann when it comes to innovation?*

Our vision statement says that we are a front runner and on the leading edge of retailing. It might not come to pass when it comes to internal functions of the company. Also we are losing some of the edge all the time due to globalisation.

*Do you expect 3D printing to have an impact on retail? What kind?*

Currently consumer level 3D printers have no impact on retail. Even as the 3D printers get better and faster I do not see that every home would have one. It is not something you would use every day. When you would need to print something out you could go to a store that offers 3D printing services.

The real use for 3D printers could be making replacement parts for stuff. But even that does not necessitate having one at home.

And the problem with spare parts is whether or not they are safe. If you are printing a spare part for a roller curtain, it is going to be okay. But if you need a spare part for a vintage car you would have to be an expert to know it can take the strain. If an amateur prints a spare part for something like a car engine, it could lead to a catastrophic failure and loss of life.

*How would you describe your knowledge of 3D printing?*

I know about it as much as I have read in the papers.